



US009074279B2

(12) **United States Patent**  
**Toihara**

(10) **Patent No.:** **US 9,074,279 B2**

(45) **Date of Patent:** **Jul. 7, 2015**

(54) **HARD LAMINAR COATING**

(75) Inventor: **Takaomi Toihara**, Toyokawa (JP)

(73) Assignee: **OSG CORPORATION**, Toyokawa-shi (JP)

(\*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 49 days.

(21) Appl. No.: **13/982,685**

(22) PCT Filed: **Feb. 1, 2011**

(86) PCT No.: **PCT/JP2011/052067**

§ 371 (c)(1),

(2), (4) Date: **Jul. 30, 2013**

(87) PCT Pub. No.: **WO2012/105001**

PCT Pub. Date: **Aug. 9, 2012**

(65) **Prior Publication Data**

US 2013/0309467 A1 Nov. 21, 2013

(51) **Int. Cl.**

**B23B 27/14** (2006.01)

**C23C 14/08** (2006.01)

**C23C 14/06** (2006.01)

**C23C 28/04** (2006.01)

**C23C 30/00** (2006.01)

**C23C 14/32** (2006.01)

**C23C 28/00** (2006.01)

(52) **U.S. Cl.**

CPC ..... **C23C 14/083** (2013.01); **Y10T 428/24975** (2015.01); **C23C 14/067** (2013.01); **C23C 28/044** (2013.01); **C23C 30/005** (2013.01); **C23C 14/0676** (2013.01); **C23C 14/08** (2013.01); **C23C 14/32** (2013.01); **C23C 28/042** (2013.01); **C23C 28/42** (2013.01)

(58) **Field of Classification Search**

USPC ..... 51/307, 309; 428/216, 336, 697, 698, 428/699, 704

See application file for complete search history.

(56) **References Cited**

**U.S. PATENT DOCUMENTS**

4,268,582 A \* 5/1981 Hale et al. .... 428/698

4,619,865 A \* 10/1986 Keem et al. .... 428/699

6,287,711 B1 \* 9/2001 Nieh et al. .... 428/697

6,770,358 B2 \* 8/2004 Berger et al. .... 51/309

8,388,709 B2 \* 3/2013 Wallgram et al. .... 51/307

2003/0039867 A1 2/2003 Berger et al.

2004/0214033 A1 10/2004 Berger et al.

2005/0170162 A1 8/2005 Yamamoto et al.

(Continued)

**FOREIGN PATENT DOCUMENTS**

CN 1845808 A 10/2006

CN 101214744 \* 7/2008

(Continued)

**OTHER PUBLICATIONS**

Mar. 8, 2011 International Search Report issued in International Application No. PCT/JP2011/052067 (with translation).

(Continued)

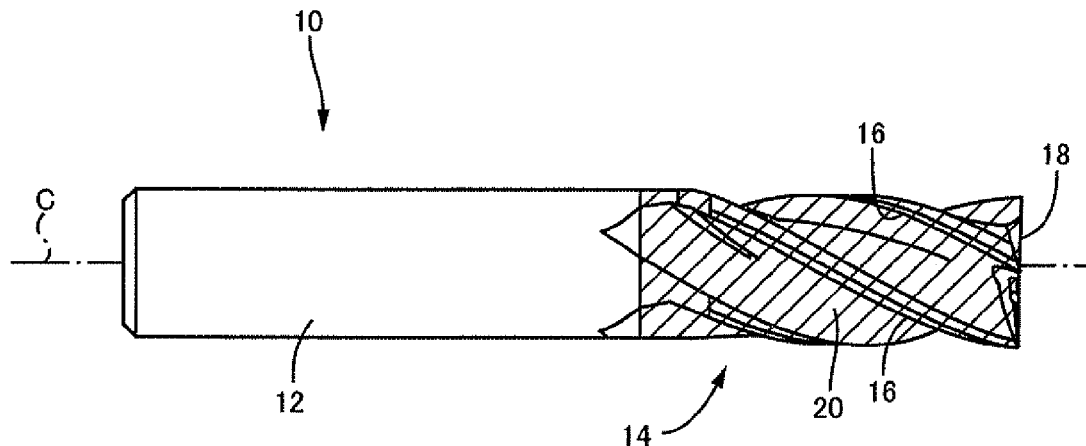
*Primary Examiner* — Archene Turner

(74) *Attorney, Agent, or Firm* — Oliff PLC

(57) **ABSTRACT**

It is provided a hard laminar coating consisting of a plurality of films including two kinds of films in the form of a first film and a second film having respective different compositions and alternately laminated on a surface of a base structure, wherein the first film is an oxide or an oxynitride of (Ti<sub>1-a</sub>B<sub>a</sub>), while the second film is TiB<sub>2</sub>.

**2 Claims, 6 Drawing Sheets**



(56)

**References Cited**

U.S. PATENT DOCUMENTS

2006/0154108 A1 7/2006 Fukui et al.  
2007/0278090 A1 12/2007 Yamamoto et al.

FOREIGN PATENT DOCUMENTS

DE 343616 \* 8/1985  
JP A-7-205361 8/1995  
JP A-10-204618 8/1998

JP A-2002-355704 12/2002  
JP 2003-291006 \* 10/2003  
JP A-2003-291007 10/2003  
JP A-2004-42149 2/2004  
JP A-2005-256081 9/2005  
JP 2008-238281 \* 10/2008

OTHER PUBLICATIONS

Nov. 28, 2014 Office Action issued in Korean Application No. 2013-7022874.

\* cited by examiner

FIG.1

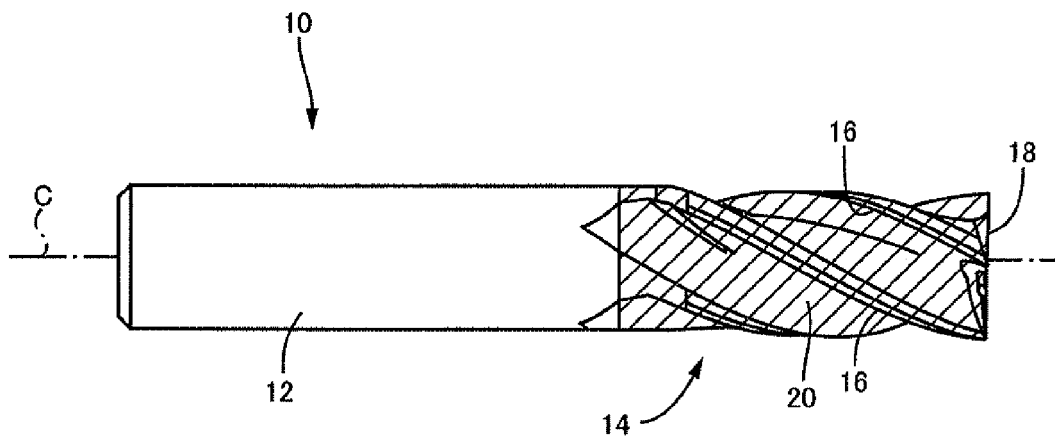


FIG.2

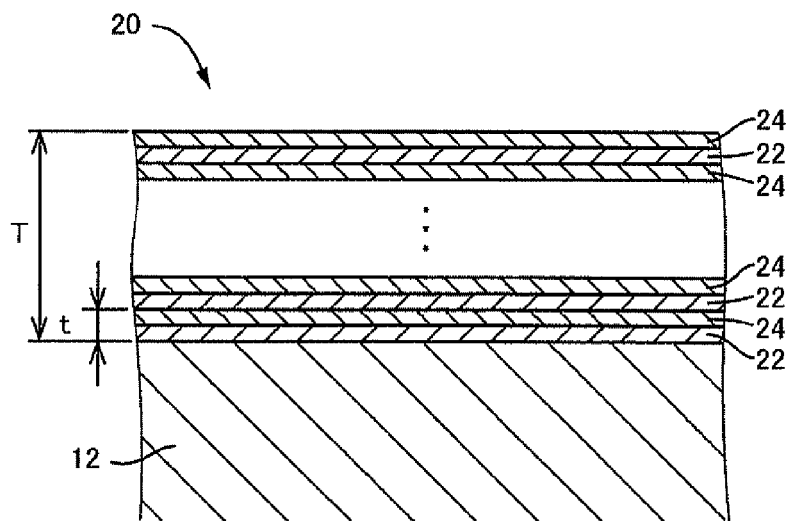


FIG.3

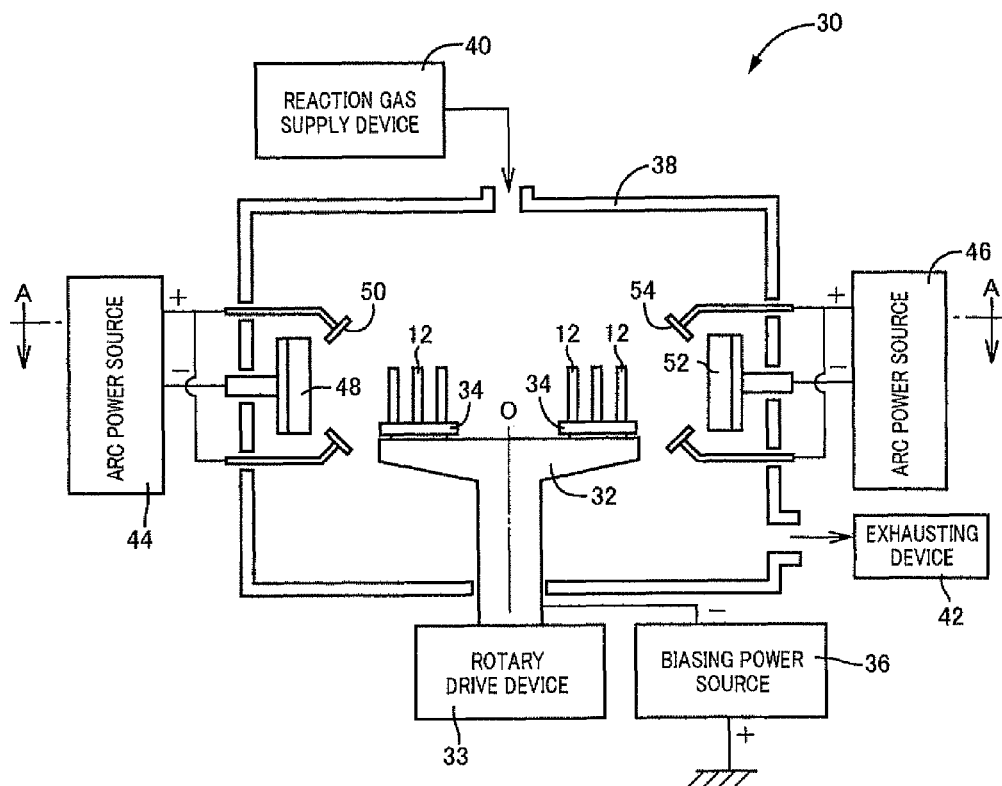


FIG.4

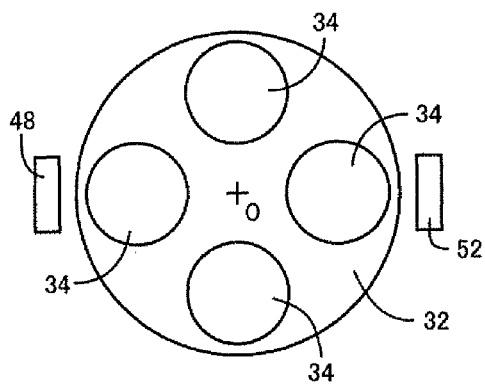


FIG.5

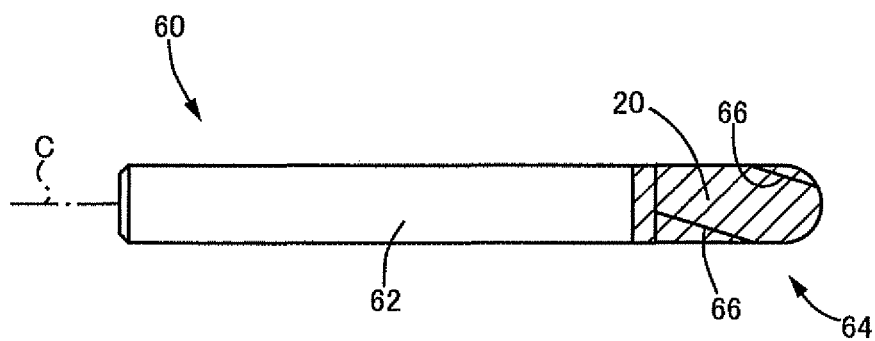


FIG.6

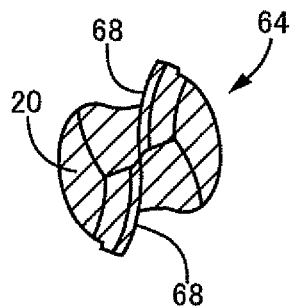


FIG. 7

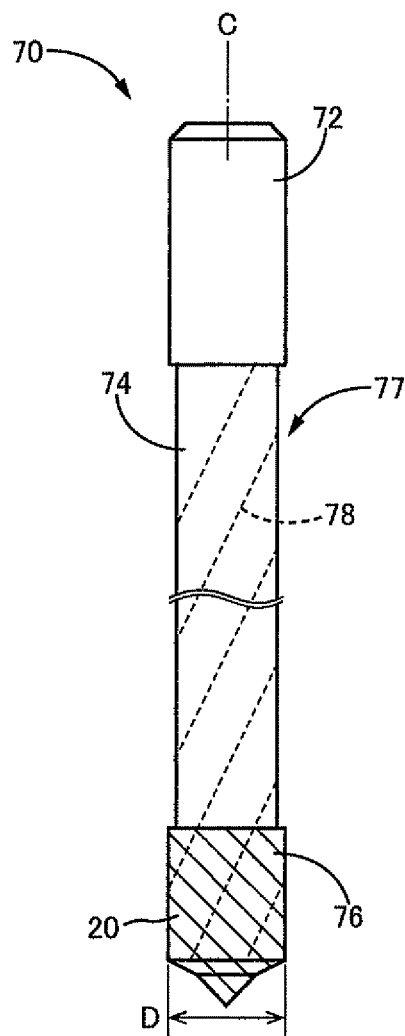


FIG. 8

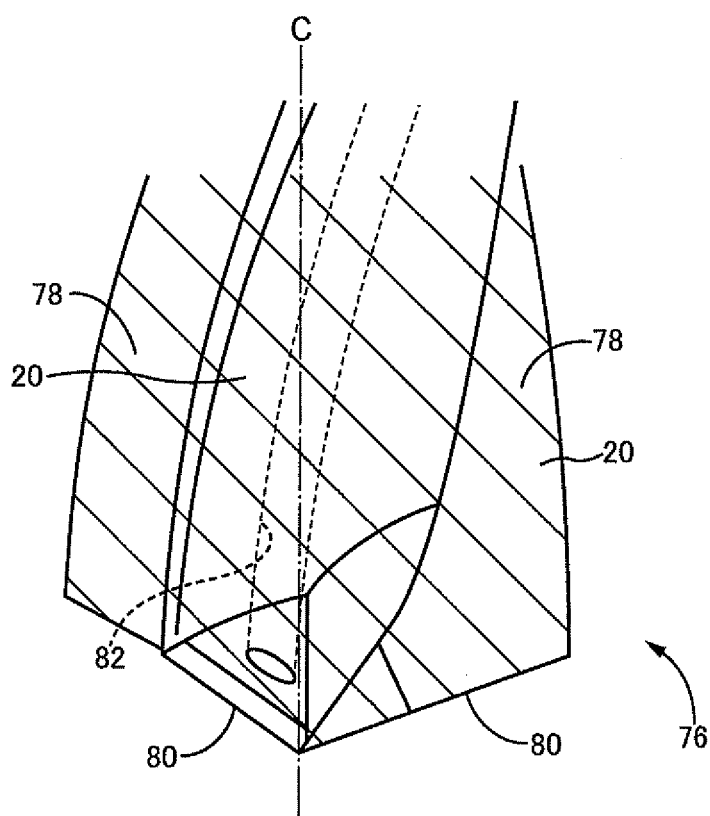


FIG. 9

TEST SAMPLES: CEMENTED CARBIDE DRILL. $\phi 8.3$									
WORKPIECE	MACHINE TOOL		CUTTING SPEED	FEED RATE	DRILLING DEPTH	MODE OF FEEDING	CUTTING FLUID		
Inconel718	VERTICAL M/C		10m/min	0.1mm/rev	33mm (BLIND HOLE)	NON-STEPPING	OIL		
TEST SAMPLES	LOWERMOST LAYER	UPPERMOST LAYER	FILM A	THICKNESS ( $\mu\text{m}$ )		TOTAL THICKNESS ( $\mu\text{m}$ )	NUMBER OF FILMS	NUMBER OF HOLES	EVALUATION
				FILM A	FILM B				
INVENTION SAMPLE 1	FILM A	FILM B	Ti0.98B0.02O	0.1	0.1	0.2	2	25	GOOD
INVENTION SAMPLE 2	FILM A	FILM B	Ti0.3B0.7ON	5.0	5.0	10.0	2	35	GOOD
INVENTION SAMPLE 3	FILM A	FILM B	Ti0.5B0.5ON	0.3	0.5	2.4	6	32	GOOD
INVENTION SAMPLE 4	FILM A	FILM B	Ti0.8B0.2O	0.3	0.2	3.6	16	41	GOOD
INVENTION SAMPLE 5	FILM A	FILM A	Ti0.95B0.05O	1.0	3.0	9.0	5	32	GOOD
INVENTION SAMPLE 6	FILM A	FILM A	Ti0.4B0.6O	0.4	0.2	7.6	25	30	GOOD
INVENTION SAMPLE 7	FILM A	FILM A	Ti0.92B0.08ON	0.1	5.0	5.2	3	29	GOOD
INVENTION SAMPLE 8	FILM A	FILM B	Ti0.7B0.3ON	3.0	0.2	3.2	2	29	GOOD
INVENTION SAMPLE 9	FILM A	FILM A	Ti0.94B0.06O	0.2	0.3	8.2	33	31	GOOD
INVENTION SAMPLE 10	FILM B	FILM B	Ti0.98B0.02O	0.1	0.1	0.3	3	27	GOOD
INVENTION SAMPLE 11	FILM B	FILM A	Ti0.3B0.7ON	4.5	4.9	9.4	2	38	GOOD
INVENTION SAMPLE 12	FILM B	FILM A	Ti0.96B0.04O	5.0	0.1	5.1	2	36	GOOD
INVENTION SAMPLE 13	FILM B	FILM B	Ti0.5B0.5O	0.3	0.3	4.5	15	43	GOOD
INVENTION SAMPLE 14	FILM B	FILM A	Ti0.92B0.08ON	0.1	0.1	10.9	100	35	GOOD
INVENTION SAMPLE 15	FILM B	FILM B	Ti0.6B0.4ON	2.0	1.0	6.1	5	31	GOOD
INVENTION SAMPLE 16	FILM B	FILM A	Ti0.8B0.2O	0.5	1.0	3.0	4	27	GOOD
INVENTION SAMPLE 17	FILM B	FILM A	Ti0.91B0.09O	1.0	2.5	3.5	2	26	GOOD
INVENTION SAMPLE 18	FILM B	FILM A	Ti0.9B0.1O	0.5	0.2	6.3	18	33	GOOD
INVENTION SAMPLE 19	FILM B	FILM B	Ti0.4B0.6ON	0.7	0.2	2.9	7	31	GOOD
PRIOR ART SAMPLE 1	-	-	TiB2	-	-	2.1	1	14	NOT GOOD
PRIOR ART SAMPLE 2	-	-	TiB2	-	-	0.3	1	8	NOT GOOD
PRIOR ART SAMPLE 3	-	-	TiB2	-	-	9.8	1	9	NOT GOOD
PRIOR ART SAMPLE 4	-	-	Ti0.5B0.5ON	-	-	3.1	1	11	NOT GOOD
PRIOR ART SAMPLE 5	-	-	Ti0.98B0.02O	-	-	5.3	1	9	NOT GOOD
PRIOR ART SAMPLE 6	-	-	Ti0.4B0.6O	-	-	8.8	1	10	NOT GOOD
COMPARATIVE SAMPLE 1	FILM A	FILM B	Ti0.99B0.01O	2.0	1.0	6.0	4	12	NOT GOOD
COMPARATIVE SAMPLE 2	FILM A	FILM B	Ti0.2B0.8ON	0.1	1.5	8.0	10	18	NOT GOOD
COMPARATIVE SAMPLE 3	FILM A	FILM B	Ti0.5B0.5ON	0.05	0.05	0.1	2	6	NOT GOOD
COMPARATIVE SAMPLE 4	FILM A	FILM B	Ti0.95B0.05O	3.0	3.0	12.0	4	15	NOT GOOD
COMPARATIVE SAMPLE 5	FILM A	FILM A	Ti0.92B0.08O	5.0	6.0	16.0	3	10	NOT GOOD
COMPARATIVE SAMPLE 6	FILM A	FILM A	Ti0.6B0.4ON	0.05	3.3	3.4	3	16	NOT GOOD
COMPARATIVE SAMPLE 7	FILM B	FILM A	Ti0.8B0.2ON	0.3	0.2	11.0	44	9	NOT GOOD
COMPARATIVE SAMPLE 8	FILM B	FILM A	Ti0.99B0.01O	0.03	0.07	0.7	2	4	NOT GOOD
COMPARATIVE SAMPLE 9	FILM B	FILM B	Ti0.2B0.8O	1.5	0.7	2.9	3	13	NOT GOOD

REMARK 1: NUMBER OF HOLES CUT BEFORE 0.2mm WEAR OF RELIEF SURFACE

REMARK 2: GOOD EVALUATION IS MADE WHERE THE NUMBER OF HOLES CUT BEFORE 0.2mm WEAR OF RELIEF SURFACE IS AT LEAST 20.



1

**HARD LAMINAR COATING****TECHNICAL FIELD**

The present invention relates to a hard laminar coating including two kinds of films having respective different compositions and alternately laminated on a surface of a base structure, and more particularly to an improvement of properties of the hard laminar coating.

**BACKGROUND ART**

Various hard laminar coatings including two kinds of films in the form of a first film and a second film having respective different compositions and alternately laminated on each other have been proposed, as a wear resistant hard laminar coating provided on a surface of a base structure of a tool of a high-speed tool steel or a cemented carbide. Patent Documents 1 and 2 disclose examples of such hard laminar coatings, wherein two kinds of films formed of metal elements belonging to the Groups IVa, Va and VIa of the Periodic Table of the Elements, or nitrides or carbides of Al, for example, are alternately laminated on each other with predetermined thicknesses of successive lamination. Namely, these hard laminar coatings are improved in the film hardness and wear resistance, owing to thickness reduction of the first and second films and increase of the number of lamination of the films, alloying of the metal elements, and various other means.

**PRIOR ART DOCUMENTS****Patent Documents**

Patent Document 1: JP-7-205361A

Patent Document 2: JP-2005-256081A

**SUMMARY OF THE INVENTION****Object Achieved by the Invention**

However, cutting tools provided with such hard laminar coatings do not exhibit sufficiently satisfactory properties in terms of their welding resistance, wear resistance and heat resistance, where the cutting tools are used to cut workpieces of heat resistant alloys such as Inconel (trademark of a nickel-based cemented carbide) and titanium alloys, or workpieces of composite materials including those heat resistant alloys.

The present invention was made in view of the background art described above. It is therefore an object of the present invention to provide a hard laminar coating which has sufficiently satisfactory properties in terms of its welding resistance, wear resistance and heat resistance where a cutting tool provided with the hard laminar coating is used to cut workpieces of heat resistant alloys such as Inconel and titanium alloys, or workpieces of composite materials including those heat resistant alloys.

**Means for Achieving the Object**

The present inventor, who made various studies in view of the above-described background art, found that a Ti-based hard laminar coating wherein one of the first and second films includes an oxide or nitride of boron (B) was satisfactory in terms of its welding resistance and heat resistance, but was not sufficient in its wear resistance and bonding strength, while a Ti-based hard laminar coating wherein one of the first and second films includes boron (B) was almost acceptable in

2

terms of its heat resistance, wear resistance and bonding strength, but was not satisfactory in its welding resistance. The present inventor tried to manufacture the hard laminar coating including the alternately laminated first and second films one of which includes an oxide or nitride of boron (B) and the other of which includes boron (B), and found that this hard laminar coating was satisfactory in terms of all of its wear resistance, heat resistance, welding resistance and bonding strength (adhesion strength). The present invention was based on this finding.

That is, according to a first aspect of this invention, there is provided a hard laminar coating (a) consisting of a plurality of films including two kinds of films in the form of a first film and a second film having respective different compositions and alternately laminated on a surface of a base structure, characterized in that (b) the above-described first film is an oxide or an oxynitride of  $(\text{Ti}_{1-a}\text{B}_a)$ , while (c) the above-described second film is  $\text{TiB}_2$ .

According to a second aspect of the invention depending from the first aspect, (d) an atomic ratio  $a$  in the above-described first film satisfies  $0.02 \leq a \leq 0.7$ , and (e) a thickness of the above-described first film is no less than  $0.1 \mu\text{m}$  and no more than  $5.0 \mu\text{m}$ , while (f) a thickness of the above-described second film is no less than  $0.1 \mu\text{m}$  and no more than  $5.0 \mu\text{m}$ , (g) the above-described hard laminar coating having a total thickness of no less than  $0.2 \mu\text{m}$  and no more than  $10.0 \mu\text{m}$ .

According to a third aspect of the invention depending from the first or second aspect, (h) the above-described hard laminar coating consists of no less than 2 and no more than 100 layers, which are laminated on each other.

**Advantages of the Invention**

The hard laminar coating according to the first aspect of this invention is formed by alternately laminating the first film of the oxide or oxynitride of  $(\text{Ti}_{1-a}\text{B}_a)$  and the second film of  $\text{TiB}_2$ , on the surface of the base structure, so that the hard laminar coating has satisfactory properties in terms of all of its wear resistance, heat resistance, welding resistance and bonding strength (adhesion strength).

According to the second aspect of the invention, the atomic ratio  $a$  of the  $(\text{Ti}_{1-a}\text{B}_a)$  in the first film satisfies  $0.02 \leq a \leq 0.7$ , and the thickness of the first film is no less than  $0.1 \mu\text{m}$  and no more than  $5.0 \mu\text{m}$ , while the thickness of the second film is no less than  $0.1 \mu\text{m}$  and no more than  $5.0 \mu\text{m}$ , the hard laminar coating having the total thickness of no less than  $0.2 \mu\text{m}$  and no more than  $10.0 \mu\text{m}$ , so that the hard laminar coating has satisfactory properties in terms of all of its wear resistance, heat resistance, welding resistance and bonding strength (adhesion strength).

The hard laminar coating according to the third aspect of the invention, the number of the first and second films alternately laminated on each other is no less than 2 and no more than 100, so that the hard laminar coating has satisfactory properties in terms of all of its wear resistance, heat resistance, welding resistance and bonding strength (adhesion strength).

The above-described hard laminar coating is preferably provided on a surface of various kinds of machining tools such as cutting tool bits and other non-rotary cutting tools, and rolling tools, as well as on a surface of at least a cutting portion of an end mill, a tapping tool, a drilling tool and other rotary cutting tools. However, the present hard laminar coating may be provided on a surface of various members other than the machining tools, as a protective coating on semiconductor devices, for example. The base structure such as the

3

base structure of a tool, on which the hard laminar coating is provided, is preferably formed of a cemented carbide or a high-speed tool steel, but may be formed of any other metallic material.

The hard laminar coating is preferably formed by a PVD process (physical vapor deposition process), such as an arc ion plating process and a sputtering process. The thicknesses of the first and second films can be suitably controlled by adjusting amounts of electric power to be applied to targets, for instance.

The atomic ratio  $a$  in  $(Ti_{1-a}B_a)$  of the above-described first film is preferably selected within a range between 0.2 and 0.7, depending upon the kinds of the metal elements and the required properties of the hard laminar coating. If the atomic ratio  $a$  is less than 0.02 or more than 0.7, the hard laminar coating cannot exhibit a satisfactory degree of wear resistance. The first film may be either an oxide or a nitride of  $(Ti_{1-a}B_a)$ .

The above-described first and second films may include inevitably contained impurity elements or other elements not influencing the properties of the hard laminar coating, other than the oxide or nitride of  $(Ti_{1-a}B_a)$  and  $TiB_2$ .

Preferably, the above-described first film has the thickness of no less than 0.1  $\mu m$  and no more than 5.0  $\mu m$ , while the second film has the thickness of no less than 0.1  $\mu m$  and no more than 5.0  $\mu m$ , and the hard laminar coating has the total thickness of no less than 0.2  $\mu m$  and no more than 10.0  $\mu m$ . If the thickness of the first or second film is less than 0.1  $\mu m$  or if the total thickness of the hard laminar coating is less than 0.2  $\mu m$ , the hard laminar coating is not satisfactory in terms of at least the wear resistance. If the thickness of the first or second film is more than 0.5  $\mu m$  or if the total thickness of the hard laminar coating is more than 10.0  $\mu m$ , the cost of manufacture of the hard laminar coating is unacceptably high.

Preferably, the number of the first and second films alternately laminated on each other is no less than 2 and no more than 100. If the number of the films is less than 2, the hard laminar coating does not include the first film or the second film, and is not satisfactory in terms of its wear resistance. If the number of the first and second films is more than 100, the cost of manufacture of the hard laminar coating is accordingly increased.

Either the first film or the second film may be formed first in contact with the surface of the base structure (of a tool, for example), depending upon the compositions of the first and second films. For example, one of the first and second films which has a higher degree of bonding strength is formed in contact with the base structure. However, the first or second film may be formed in contact with the base structure, irrespective of their compositions. The first and second films may be alternately laminated on each other as a pair or a plurality of successive pairs, but an odd total number of the first and second films may be laminated on each other such that the first film is formed as the lowermost and uppermost layers, or the second film is formed as the lowermost and uppermost layers. It is noted that a hard film other than the first and second films may be interposed between the surface of the base structure and the present hard laminar coating, as needed, and another film may be formed on the uppermost layer.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a view showing an end mill to which a hard laminar coating of the present invention is applicable, the view being a front elevational view as seen in a direction perpendicular to an axis of the end mill;

4

FIG. 2 is a view showing the end mill of FIG. 1, the view being a cross sectional view showing in enlargement the hard laminar coating provided on a surface of a cutting portion of the end mill;

FIG. 3 is a schematic view showing an example of an arc ion plating device configured to suitably form the hard laminar coating of FIG. 1 in a PVD process;

FIG. 4 is a plane view for explaining a positional relationship between a rotary table and targets of the arc ion plating device of FIG. 3;

FIG. 5 is a front elevational view of a ball end mill to which the hard laminar coating of the present invention is applicable, as seen in the direction perpendicular to the axis of the ball end mill;

FIG. 6 is an end view of the cutting portion of the ball end mill of FIG. 5, as seen in the axial direction of the ball end mill;

FIG. 7 is a front elevational view of a drill to which the hard laminar coating of the present invention is applicable, as seen in a direction perpendicular to the axis of the drill;

FIG. 8 is a perspective view showing a cutting portion of the drill of FIG. 7; and

FIG. 9 is a view indicating composition, thickness, number of the films and evaluated wear resistance of the hard laminar coatings formed on the cutting portion of the drill of FIG. 7, as compared with those of comparative samples not satisfying the numerical requirements of the present invention and prior art samples wherein the hard laminar coating includes only one kind of film.

#### MODE FOR CARRYING OUT THE INVENTION

Referring to the drawings, embodiments of the present invention will be described in detail.

##### First Embodiment

FIG. 1 is the view showing an end mill 10 which is an example of a tool to which a hard laminar coating of the present invention is applicable, the view being a front elevational view as seen in a direction perpendicular to an axis C of the end mill 10. This end mill 10 has a tool base structure 12 formed of a cemented carbide and consisting of a shank and a cutting portion 14. The cutting portion 14 has integrally formed helical peripheral cutting edges 16 and a linear end cutting edge 18 as cutting edges. The cutting portion 14 is rotated about the axis C to perform a cutting operation with the peripheral cutting edges 16 and end cutting edge 18, and is coated on its surface with a hard laminar coating 20. A hatched area in FIG. 1 shows the hard laminar coating 20.

FIG. 2 is the cross sectional view showing in enlargement structure of the hard laminar coating 20 provided on the surface of the cutting portion 14. The end mill 10 is a rotary cutting tool, and the tool base structure 12 corresponds to a base body having a surface on which the hard laminar coating 20 is provided.

As is apparent from FIG. 2, the hard laminar coating 20 consists of a multiplicity of layers formed on a surface of the tool base structure 12 by alternately laminating a first film 22 and a second film 24 of respective different compositions on each other. The first film 22 is formed of an oxide or an oxynitride of an alloy of  $(Ti_{1-a}B_a)$ . The atomic ratio  $a$  of the alloy of  $(Ti_{1-a}B_a)$  satisfies  $0.02 \leq a \leq 0.7$ , and the thickness of the first film 22 is no less than 0.1  $\mu m$  and no more than 5.0  $\mu m$ . The second film 24 is formed of an alloy of  $TiB_2$ . The thickness of the second film 24 is no less than 0.1  $\mu m$  and no more than 5.0  $\mu m$ . The hard laminar coating 20 including the

5

alternately laminated first and second films 22, 24 consists of no less than 2 and no more than 100 layers, and has a thickness of no less than 0.2  $\mu\text{m}$  and no more than 10.0  $\mu\text{m}$ .

FIG. 3 is the schematic view showing an arc ion plating device 30 suitably used to form the above-described hard laminar coating 20. FIG. 4 is the plane view taken along lines A-A of FIG. 3. This arc ion plating device 30 is provided with: a first rotary table 32 having a substantially horizontal support surface; a rotary drive device 33 for rotating the first rotary table 32 about a substantially vertical axis O; a plurality of (four in the example of FIG. 4) second rotary tables 34 disposed in a radially outer portion of the first rotary table 32 and holding a multiplicity of workpieces in the form of the tool base structures 12 having the cutting edges 16, 18 to be coated with the hard laminar coating 20; a biasing power source 36 for applying a negative bias voltage to the tool base structures 12; a chamber 38 serving as a processing container accommodating therein the tool base structures 12, etc.; a reaction gas supply device 40 for supplying a suitable reaction gas into the chamber 38; an exhausting device 42 provided with a vacuum pump for exhausting a gas out of the chamber 38, and thereby reducing the pressure within the chamber 38; a first arc power source 44; a second arc power source 46; etc. The arc ion plating device 30 corresponds to a coating forming device. It is noted that the tool base structures 12 held by the second rotary tables 34 are not shown in FIG. 4.

The above-described second rotary tables 34 are disposed in parallel to the first rotary table 32, such that each of the second rotary tables 34 is rotated about its axis (second axis) which is parallel to the axis O of the first rotary table 32. Each second rotary table 34 holds a plurality of the tool base structures 12 such that each tool base structure 12 stands upright with its axis being parallel to the above-indicated second axis and with its cutting portion 14 being located on its upper side, so that each of the tool base structures 12 is rotated about the axis of the second rotary table 34 (about the second axis) while at the same time rotated about the axis O of the first rotary table 32. Around the first rotary table 32, there are fixedly disposed a first target 48 and a second target 52, which are spaced apart from each other by 180° about the axis O. As the first rotary table 32 is continuously rotated, the tool base structures 12 are moved cyclically and alternately in front of the first and second targets 48, 52, together with the second rotary tables 34. In the present embodiment, the two targets in the form of the first and second targets 48, 52 are disposed in the 180° spaced-apart relationship with each other about the axis O. While the present embodiment is configured such that the plurality of second rotary tables 34 are rotated by respective rotary drive devices independently of the rotation of the first rotary table 32, the second rotary tables 34 may be mechanically connected through a gear or other mechanism to the first rotary table 32 so that the second rotary tables 34 are rotated in synchronization with the rotation of the first rotary table 32.

The above-indicated reaction gas supply device 40 is provided with reservoirs storing a nitrogen ( $\text{N}_2$ ) gas, a hydrocarbon ( $\text{CH}_4$ ,  $\text{C}_2\text{H}_2$ , etc.) gas, an oxygen ( $\text{O}_2$ ) gas, etc., and supplies the appropriate gas or gases depending upon the compositions of the first and second films 22, 24 to be formed. For example, only the oxygen gas is supplied to form an oxide, or only the nitrogen gas is supplied to form a nitride. The oxygen gas and the nitrogen gas are supplied to form an oxynitride, or the nitrogen gas and the hydrocarbon gas are supplied to form a carbonitride. The appropriate gases are supplied to form other compounds such as a boronitride.

The first target 48 disposed to face the above-indicated axis O is formed of an alloy of  $(\text{Ti}_{1-a}\text{B}_a)$  which provides the

6

components of the first film 22, while the second target 52 also disposed to face the axis O is formed of an alloy of  $\text{TiB}_2$  which provides the components of the second film 24. The above-indicated first arc power source 44 applies a predetermined arc current between a cathode in the form of the above-indicated first target 48 and an anode 50, to perform an arc discharge for vaporizing the alloy of  $(\text{Ti}_{1-a}\text{B}_a)$  from the first target 48 so that the vaporized alloy of  $(\text{Ti}_{1-a}\text{B}_a)$  is deposited as positive (+) metal ions on the tool base structures 12 to which the negative bias voltage is applied. At this time, the vaporized alloy of  $(\text{Ti}_{1-a}\text{B}_a)$  reacts with the supplied reaction gas or gases, to form an oxide or an oxynitride of  $(\text{Ti}_{1-a}\text{B}_a)$  for thereby forming the first film 22. The above-indicated second arc power source 46 applies a predetermined arc current between a cathode in the form of the above-indicated second target 52 and an anode 54, to perform an arc discharge for vaporizing the alloy of  $\text{TiB}_2$  from the second target 52 so that the vaporized alloy of  $\text{TiB}_2$  is deposited as positive (+) metal ions on the tool base structures 12 to which the negative bias voltage is applied.

When the hard laminar coating 20 is formed on the surface of the cutting portion 14 of each tool base structure 12, by using the arc ion plating device 30 constructed as described above, the predetermined reaction gas or gases is/are supplied from the reaction gas supply device 40 while the pressure within the chamber 38 is held at a predetermined level (e.g. within a range between about 1.33 Pa and about 3.99 Pa) by the operation of the exhausting device 42, and the predetermined bias voltage (e.g. within a range between about -50V and about -150V) is applied from the bias power source 36 to the tool base structures 12. At the same time, the first rotary table 32 is continuously rotated about the axis O in one direction at a constant speed while the second rotary tables 34 are rotated about their axes, so that the tool base structures 12 are moved cyclically and alternately in front of the first and second targets 48, 52, together with the second rotary tables 34, while the tool base structures 12 are rotated about the second axis.

The first film 22 formed of the oxide or oxynitride of  $(\text{Ti}_{1-a}\text{B}_a)$  is deposited on the surface of the tool base structure 12 when the tool base structure 12 is moved in front of the first target 48, while the second film 24 formed of  $\text{TiB}_2$  is deposited on the surface of the tool base structure 12 when the tool base structure 12 is moved in front of the second target 52. Thus, the first film 22 and the second film 24 are alternately and repeatedly laminated on the surface of the tool base structure 12, to form the hard laminar coating 20. In the present embodiment, the first and second targets 48, 52 are disposed around the first rotary table 32, so that the first film 22 and the second film 24 are laminated on each other during rotation of the first rotary table 32. The amounts of the arc current applied from the respective arc power sources 44, 46 are determined according to the thicknesses of the first and second films 22, 24 to be formed. The formation of this hard laminar coating 20 can be automatically controlled by a control device including a computer.

Since the first film 22 is formed of an oxide or oxynitride of  $(\text{Ti}_{1-a}\text{B}_a)$  while the second film 24 is formed of  $\text{TiB}_2$ , the first and second films 22, 24 must be formed independently of each other, so that the reaction gas or gases to be supplied from the reaction gas supply device 40 is/are changed, and the first and second arc power sources 44, 46 are selectively turned on and off to selectively turn on and off the first and second targets 48, 52.

#### Second Embodiment

FIG. 5 is the front elevational view of a ball end mill 60 having a cutting portion 64 on which the hard laminar coating

20 is formed in a process similar to that for the end mill 10 in the first embodiment, as seen in the direction perpendicular to the axis C of the ball end mill 60, and FIG. 6 is the end view of the cutting portion 64 of the ball end mill 60 as seen in its axial direction. This ball end mill 60 has a tool base structure 62 formed of a cemented carbide and consisting of a shank and the cutting portion 64. The cutting portion 64 has integrally formed helical peripheral cutting edges 66 and two semicircular ball (end) cutting edges 68 as cutting edges. The cutting portion 64 is rotated about the axis to perform a cutting operation with the peripheral cutting edges 66 and ball cutting edges 68, and is coated on its surface with the hard laminar coating 20 as shown in FIG. 2. Hatched areas in FIGS. 5 and 6 show the hard laminar coating 20.

### Third Embodiment

FIG. 7 is the front elevational view of a drill 70 having a tip end cutting portion 76 on which the above-described hard laminar coating 20 is formed in a process similar to that for the end mill 10 in the first embodiment, as seen in a direction perpendicular to the axis C of the drill 70, and FIG. 8 is the perspective view showing the tip end cutting portion 76. For example, this drill 70 is a twist drill having three cutting edges formed integrally with a body of a cemented carbide. Namely, the twist drill 70 has a tool base structure 77 in the form of an elongate body of a cemented carbide consisting of a shank 72 to be held by the main spindle, a shaft portion 74 and the tip end cutting portion 76, which are formed in this order of description in the axial direction. The tip end cutting portion 76 has a diameter D slightly larger than that of the shaft portion 74, and functions as a cutting edge primarily to cut a hole. The end cutting portion 76 is coated on its surface with the hard laminar coating 20 shown in FIG. 2. Hatched areas in FIGS. 7 and 8 show the hard laminar coating 20.

The above-indicated shaft portion 74 and end cutting portion 76 have three spiral grooves 78 formed equiangularly spaced apart from each other about an axis C of the drill, and primary cutting edges (end cutting edges) 80 formed at the open end of the respective spiral grooves 78 at a tip end of the tip end cutting portion 76, along the open end edges of the respective spiral grooves 78. A cutting-fluid supply hole 82 is open in a relief surface of one of the primary cutting edges 80, which is an end face of the end cutting portion 76.

A plurality of different kinds of test samples of the above-described drill 70 were manufactured by coating the surface of the end cutting portion 76 with the respective hard laminar coatings having respective different combinations of the compositions, thicknesses and number of lamination of the films, as indicated in FIG. 9. Test drilling operations were performed with the test sample drills under the following drilling conditions, and the test sample drills were evaluated on the basis of the number of holes that could be cut by the test sample drills. Results of the evaluation are also indicated in FIG. 9. In FIG. 9, film A corresponds to the first film 22, while film B corresponds to the second film 24. The last characters "O", "N" and "ON" of the representation of the composition of the film A respectively indicate an oxide, a nitride and an oxynitride. The number of holes indicated in FIG. 9 is the number of the holes that could be cut by the drill of each test sample before 0.2 mm wear of the relief surface adjacent to the primary (end) cutting edges 80 was recognized. The wear resistance of each test sample drill was evaluated depending upon the number of the holes cut, and "Good" evaluation was made where the number of the holes cut is more than 20.

### <Conditions of Test Drilling Operations>

Drill: Cemented carbide drill ( $\phi 8.3$  mm) coated with the hard laminar coating

Workpiece: Inconel 718 (trademark of a nickel-based cemented carbide)

Machine tool used: Vertical machining center

Cutting speed: 10 m/min.

Feed rate: 0.1 mm/rev.

Drilling depth: 33 mm (blind hole)

Mode of feeding: Non-stepping

Cutting fluid: Oil

In the above-described test drilling operations, all of the test sample drills coated with the hard laminar coatings 20 each including the alternately laminated first and second films 22, 24 exhibited satisfactory properties in terms of welding resistance, heat resistance and bonding strength, but these test sample drills exhibited different degrees of wear resistance, as indicated in FIG. 9. Namely, in FIG. 9 "Invention Samples 1-19" which are the drills coated with the hard laminar coating 20 including the alternately laminated first and second films 22, 24 were given "good" evaluation of the wear resistance, and "Comparative Samples 1-9" which are also the drills coated with the hard laminar coating 20 were given "not good" evaluation of the wear resistance. "Prior Art Samples 1-6" are drills coated with respective hard laminar coatings each using only one kind of film.

In each of the "Invention Samples 1-19" given the "good" evaluation of the wear resistance, the hard laminar coating 20 covering its cutting portion includes the first film 22 (film A) formed of an oxide or an oxynitride of the alloy of ( $Ti_{1-a}B_a$ ) and the second film 24 (film B), which are alternately laminated on each other. Further, the atomic ratio a of the alloy of ( $Ti_{1-a}B_a$ ) satisfies  $0.02 \leq a \leq 0.7$ , and the thickness of the first film 22 is no less than 0.1  $\mu m$  and no more than 5.0  $\mu m$ . The second film 24 is formed of the alloy of  $TiB_2$ , and the thickness of the second film 24 is no less than 0.1  $\mu m$  and no more than 5.0  $\mu m$ . The number of the first and second films 22, 24 alternately laminated on each other to form the hard laminar coating 20 is no less than 2 and no more than 100, and the hard laminar coating 20 has the thickness of no less than 0.2  $\mu m$  and no more than 10.0  $\mu m$ . All of these "Invention Samples 1-19" were given the "good" evaluation of the wear resistance, irrespective of whether the first film 22 (film A) or the second film 24 (film B) is the lowermost layer, or the uppermost layer, as indicated in FIG. 9.

On the other hand, the "Comparative Samples 1-9" were given the "not good" evaluation of the wear resistance. These samples were also coated with the hard laminar coatings 20 each of which includes the alternately laminated with first and second films 22, 24 at the cutting edges and wherein the first film 22 is formed of an oxide or oxynitride of ( $Ti_{1-a}B_a$ ) while the second film 24 is formed of  $TiB_2$ . However, any one of the atomic ratio a, the film thicknesses and the number of the films alternately laminated on each other is outside a corresponding one of the ranges of the present invention described above. Further, the "Prior Art Samples 1-6" wherein the hard laminar coating uses only one kind of film exhibited considerably low degrees of wear resistance, and also failed to exhibit satisfactory properties in terms of at least one of its welding resistance, heat resistance and bonding strength that is not shown in FIG. 9.

The illustrated embodiments described above are configured such that the hard laminar coating 20 includes the first film 22 of an oxide or an oxynitride of ( $Ti_{1-a}B_a$ ) and the second film 24 formed of  $TiB_2$ , which are alternately laminated on a surface of the base structure 12, 62, 77, so that the hard laminar coating 20 has satisfactory properties in terms of

all of its wear resistance, heat resistance, welding resistance, and bonding strength (adhesion strength).

The illustrated embodiments are further configured such that the atomic ratio  $a$  in  $(\text{Ti}_{1-a}\text{B}_a)$  of the first film **22** satisfies  $0.02 \leq a \leq 50.7$ , and the thickness of the first film **22** is no less than  $0.1 \mu\text{m}$  and no more than  $5.0 \mu\text{m}$ , while the thickness of the second film **24** is no less than  $0.1 \mu\text{m}$  and no more than  $5.0 \mu\text{m}$ , and such that the hard laminar coating **20** has the total thickness of no less than  $0.2 \mu\text{m}$  and no more than  $10.0 \mu\text{m}$ , so that the hard laminar coating **20** has satisfactory properties in terms of all of its wear resistance, heat resistance, welding resistance, and bonding strength (adhesion strength).

The illustrated embodiments are also configured such that the number of the first and second films **22**, **24** of the hard laminar coating **20** alternately laminated on each other is no less than 2 and no more than 100, so that the hard laminar coating **20** has satisfactory properties in terms of all of its wear resistance, heat resistance, welding resistance and bonding strength (adhesion strength).

While the embodiments of the present invention have been described above in detail by reference to the drawings, for illustrative purpose only, it is to be understood that the present invention may be embodied with various changes and improvements, which may occur to those skilled in the art.

#### INDUSTRIAL UTILITY

The hard laminar coating **20** according to the present invention includes the first film **22** formed of an oxide or an oxynitride of  $(\text{Ti}_{1-a}\text{B}_a)$  and the second film **24** formed of  $\text{TiB}_2$ , which are alternately laminated on a surface of the tool base structure **12**, **62**, **77**, so that the hard laminar coating **20** has satisfactory properties in terms of all of its wear resistance, heat resistance, welding resistance, and bonding strength (ad-

hesion strength). The hard laminar coating **20** having the particularly improved wear resistance can be suitably used as a hard coating for rotary cutting tools, etc.

#### NOMENCLATURE OF REFERENCE SIGNS

- 10**: End mill (Cutting tool provided with a hard laminar coating)
- 12, 62, 77**: Base structure of tools
- 20**: Hard laminar coating
- 22**: First film
- 24**: Second film
- 60**: Ball end mill (Cutting tool provided with a hard laminar coating)
- 70**: Drill (Cutting tool provided with a hard laminar coating)

The invention claimed is:

**1.** A hard laminar coating consisting of a plurality of films including two kinds of films in the form of a first film and a second film having respective different compositions and alternately laminated on a surface of a base structure, wherein said first film is an oxide or an oxynitride of  $(\text{Ti}_{1-a}\text{B}_a)$ , while said second film is  $\text{TiB}_2$

wherein an atomic ratio  $a$  in said first film satisfies  $0.02 \leq a \leq 0.7$ , and a thickness of said first film is no less than  $0.1 \mu\text{m}$  and no more than  $5.0 \mu\text{m}$ , while a thickness of said second film is no less than  $0.1 \mu\text{m}$  and no more than  $5.0 \mu\text{m}$ , said hard laminar coating having a total thickness of no less than  $0.2 \mu\text{m}$  and no more than  $10.0 \mu\text{m}$ .

**2.** The hard laminar coating according to claim 1, wherein said hard laminar coating consists of no less than 2 and no more than 100 layers, which are laminated on each other.

\* \* \* \* \*